# Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Farmed Trees by Fermentation
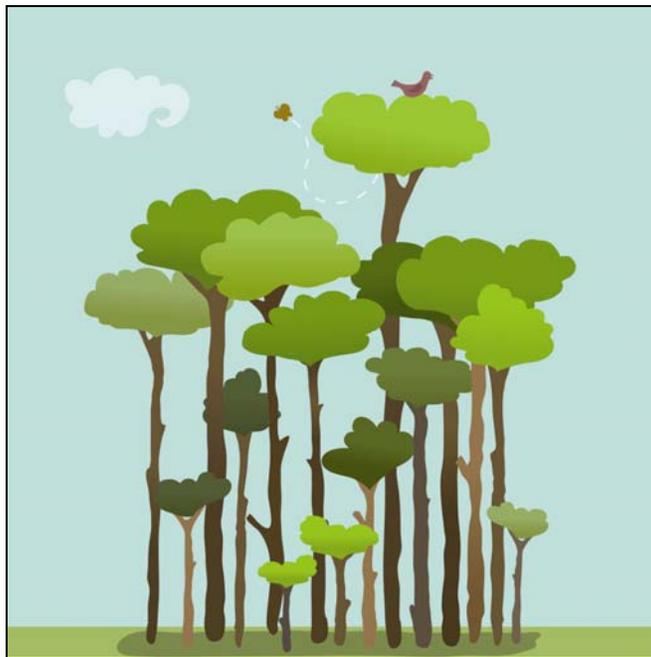
This is a preliminary estimate of the carbon intensity for the fuel derived from the feedstock presented in this document. At this time, this document has been provided for informational purposes only. Staff is in the process of obtaining additional information to refine and/or modify the values presented in this document. The refinement is both for direct and indirect effects. When staff has completed the analysis, a final value will be presented in the future for the fuel presented in this document.

Stationary Source Division

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When reviewing this document, please submit comments directly to:
Anil Prabhu: aprabhu@arb.ca.gov
Chan Pham: cpham@arb.ca.gov
Alan Glabe: aglabe@arb.ca.gov
Jim Duffy: jduffy@arb.ca.gov

These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner

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SUMMARY

CA-GREET Model Pathway for Farmed Trees Ethanol

A Well-To-Tank (WTT) Life Cycle Analysis of a fuel (or blending component of fuel) pathway includes all steps from feedstock production to final finished product. Tank-To-Wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together WTT and TTW analysis are combined together to provide a total Well-To-Wheel (WTW) analysis.

A Life Cycle Analysis Model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET)[1] developed by Argonne National Laboratory has been used to calculate the energy use and Greenhouse gas (GHG) emissions and consequent GHG emissions generated during the entire process from farmed trees growing, farmed trees processing to ethanol and transportation to a blending station. The model however, was modified by TIAX under contract to the California Energy Commission during the AB 1007 process[2]. Changes were restricted to mostly input factors (electricity generation factors, crude transportation distances, etc.) with no changes in methodology inherent in the original GREET model. This California-modified GREET model formed the basis for fuel pathways published by staff in mid-2008. Subsequent to this, the Argonne Model was updated in September 2008. To reflect the update and to incorporate other changes, staff contracted with Life Cycle Associates to update the CA-GREET model. This updated California modified GREET model (v1.8b) (released February 2009)[3] forms the basis of this document. It has been used to calculate the energy use and greenhouse gas (GHG) emissions associated with a WTW analysis of ethanol produced from farmed trees.

This document details the energy and inputs required to produce ethanol from farmed trees outside of California and transport the ethanol by rail to blending terminals in California for blending with CARBOB (CA gasoline blendstock). The small diameter farmed trees could be poplar, pine, eucalyptus, or genetically engineered trees. Well-to-tank greenhouse gas emissions are also calculated based on the energy results and provided in this document.

Figure 1 below outlines the discrete components that comprise the farmed trees ethanol pathway, from trees farming to ethanol transport and distribution. Note that anhydrous ethanol (which is distilled ethanol >99.6% purity) has been used as the basis for all calculations in this document. Ethanol is not considered to be used as a fuel by itself in California. It is blended with CARBOB to produce CaRFG[1] which is used as a fuel in California. The CaRFG document includes blending details of ethanol with CARBOB and is available on the LCFS website.

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[1] CaRFG is actually blended with 10% ethanol (by volume, nominal). RFG without ethanol is potentially also a fuel, but the fuel cycle energy inputs would differ somewhat from CARBOB. In California, CARBOB by itself cannot be used as a motor vehicle fuel but needs to be blended with an oxygenate before use.

Several general descriptions and clarification of terminology used throughout this document are:

- CA-GREET employs a recursive methodology to calculate energy consumption and emissions. To calculate WTT energy and emissions, the values being calculated are often utilized in the calculation. For example, crude oil is used as a process fuel to recover crude oil. The total crude oil recovery energy consumption includes the direct crude oil consumption and the energy associated with crude recovery (which is the value being calculated).
- Btu/mmBtu is the energy input necessary in Btu to produce one million Btu of a finished (or intermediate) product. This description is used consistently in CA-GREET for all energy calculations.
- gCO_2e/MJ provides the total greenhouse gas emissions on a CO_2 equivalent basis per unit of energy (MJ) for a given fuel. Methane (CH_4) and nitrous oxide (N_2O) are converted to a CO_2 equivalent basis using IPCC (Intergovernmental Panel on Climate Change) global warming potential values and included in the total.
- CA-GREET assumes that VOC and CO are converted to CO_2 in the atmosphere and includes these pollutants in the total CO_2 value using ratios of the appropriate molecular weights.
- Process Efficiency for any step in CA-GREET is defined as:

   Efficiency = energy output / (energy output + energy consumed)

- Note that rounding of values has not been performed in several tables in this document. This is to allow stakeholders executing runs with the CA-GREET model to compare actual output values from the CA-modified model with values in this document.
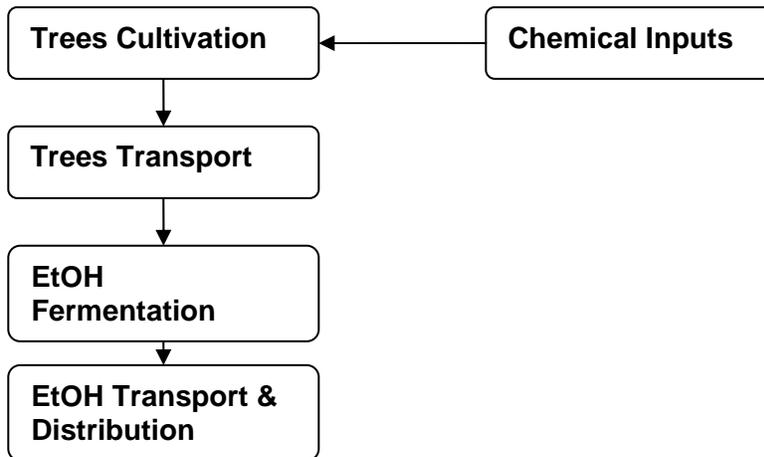
Figure 1. WTT Components for Ethanol Transported to California

Table A below summarizes the fuel cycle energy inputs by stage (Btu/mmBtu) and Table B summarizes the major GHG emission categories and intensities (gCO_2e/MJ). The Tables present energy and emission results relative to the energy content (LHV) of anhydrous ethanol. Complete details of all energy inputs and GHG emissions are

provided in Appendix A. A list of all inputs is provided in Appendix B. Due to negative values resulting from co-product credits, all percentages have not been calculated.

Table A. Energy Use by Stage for Ethanol from Farmed Trees Pathway

Farmed Trees Ethanol WTT Components	Energy[*] (Btu/mmBtu)	% Energy Contribution
Farmed Trees Cultivation	42,637	
Energy Inputs for Ag Chemicals	6,515	
Farmed Trees Transportation	28,907	
Ethanol Production	1,452,984	
Ethanol T&D	30,132	
Co-gen Credit	-47,059	
Storage	0	
Total well-to-tank	**1,514,116**	**60.22%**
Neat Ethanol	1,000,000	39.78%
Total tank-to-wheel	**1,000,000**	**39.78%**
Total well-to-wheel	**2,514,116**	100%

Table B. GHG Emissions Summary for Ethanol from Farmed Trees Pathway

Farmed Trees Ethanol Fuel Cycle Components	GHGs	% Emission Contribution
Farmed Trees Cultivation	3.34	
Ethanol Production	2.56	
Ag Chemicals Production and Use (inclusive of N_2O release from fertilizer)	1.10	
Farmed Trees Transportation	2.10	
Ethanol T&D	2.70	
Co-Gen Credit	-10.20	
Total well-to-tank	**1.60**	**100%**
Total tank-to-wheel	**0**	**0**
Total well-to-wheel	**1.60***	**100%**

* Note: Ethanol is not used directly as a fuel in CA but blended with CARBOB to produce CaRFG. Use of CaRFG in a light-duty vehicle generates CO_2 and other tailpipe emission species. When these are added (appropriately weighted) to the value in the Table above, the WTW GHG emissions is calculated to be **2.40 gCO$_2$e/MJ** for cellulosic ethanol from farmed trees as detailed in this document.   Details of this calculation are provided in the CaRFG document. Also, a preliminary Land Use

Change analysis has been conducted by staff for non-food crop based cellulosic feedstocks. This is detailed in Chapter 4 of the staff report. An estimate of 18 gCO_2e/MJ has been estimated for cellulosic feedstock grown on marginal land. This is preliminary and staff is in the process of refining the analysis and an update will be provided when the analysis is completed. Using this preliminary value of 18.0 gCO_2e/MJ for Land Use Change, the total carbon intensity for the Farmed Trees derived ethanol is estimated to be **20.40 gCO_2e/MJ**.

WTT Details

This section provides a breakdown of the various energy and related GHG emissions for all the various components of the ethanol pathway detailed in Figure 1. Complete details including calculations, equations, etc. are provided in Appendix A.

FARMED TREES CULTIVATION

Table C provides a breakdown of energy input from each fuel type used in trees farming activities. Table D provides information on GHG emissions related to the use of energy for trees farming. Additional details are provided in Appendix A.

Table C. Total Energy Input by Fuel for Trees Cultivation

Fuel Type	Total Energy (Btu/dry ton)
Diesel fuel	257,478
Electricity	35,412
Total Energy for trees cultivation for ethanol (Btu/ dry ton)	292,904
Total Energy for trees cultivation for ethanol (Btu/mmBtu)	**42,637**

Table D. GHG Emissions from Trees Cultivation

Farmed Trees Cultivation	By Fermentation
Emission Species	GHG ($gCO_2e/mmBtu$)
VOC	12.2
CO	21.5
CH_4	100.0
N_2O	13.5
CO_2	3,345
Total GHG ($gCO_2e/mmBtu$)	3,526
Total GHG (gCO_2e/MJ)	**3.34**

CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS

Table E provides details the energy inputs required to produce various chemicals used in agricultural operations related to trees farming. Table F provides details of the associated GHG emissions related to the production of these chemicals.

Table E. Energy Inputs for Agricultural Chemicals for Trees Farming

Chemical Type	Energy Use, (Btu/mmBtu)
Nitrogen Fertilizer	4,731
Phosphate Fertilizer	366
Potash	406
Herbicide (average)	922
Insecticide (average)	91
Total	**6,515**

Table F. Total GHG Emissions from Agricultural Chemical Use

GHGs	Fertilizers	Herbicide	Pesticide	N_2O from fertilizer use	Total
gCO_2e/MJ	0.32	0.03	0.03	0.6	**1.1**

FARMED TREES TRANSPORT

Table G details the energy inputs required to transport farmed trees from the farm to the ethanol production plant. Table H provides details of the associated GHG emissions related to transportation of farmed trees from the farm to the ethanol plant.

Table G. Energy for Farmed Trees Transport

Transport Mode	Energy Consumption
Trees Field to Ethanol Plant by Heavy Duty Truck (Btu/dry ton)	198,591
Total in (Btu/mmBtu)	**28,907**

Table H. Transport of Farmed Trees – Total GHG Emissions

Transport Mode	GHG Emissions (gCO$_2$e/mmBtu)
Field to Ethanol Plant by Heavy Duty Truck	2,222
Total (g CO$_2$e/MJ)	**2.1**

ETHANOL PRODUCTION

Table I details the energy inputs required to produce ethanol from farmed trees by fermentation. Table J provides details of the associated GHG emissions related to production of ethanol. It includes the impacts of burning the lignin from the trees as energy for production of ethanol.

Table I. Energy Use for Ethanol Production by Fermentation

Fuel Type	Total Energy
Diesel (Btu/gal)	391.8
Direct use from farmed tree (Btu/gal)	110,459
Total energy input for ethanol production (Btu/gal)	110,851
Total energy input for ethanol production (converted to Btu/mmBtu)	**1,452,984**

Table J. GHG Emissions for Ethanol Production by Fermentation

GHG Species	g/mmBtu	g CO$_2$e/MJ
VOC	6.0	
CO	85.2	
CH$_4$	11.5	
N$_2$O	6.85	
CO$_2$	112,972	
Total GHGs (gCO$_2$e/mmBtu)	115,527	**109.5**
CO$_2$ credit from direct use of tree burning as process fuel	(-112,751)	**(-106.9)**
Total GHGs	**2,702**	**2.56**

ETHANOL TRANSPORT AND DISTRIBUTION

Transport from the ethanol plant to the bulk terminal or storage facility is accomplished primarily by rail (with short truck delivery to terminal or storage facility). The local distribution step involves transporting ethanol to a gasoline blending terminal where it is blended with gasoline to produce RFG. Ethanol is transported by truck to the blending terminal. Table K details the energy inputs required to transport ethanol. Table L

provides details of the associated GHG emissions related to ethanol transport and distribution.

Table K. Energy Use for Ethanol Transport and Distribution (T&D)

Transport Mode	Btu/mmBtu
Transportation by Rail	27,512
Distribution by Truck	2,620
T&D Total (Btu/mmBtu Anhydrous)	**30,132**

Table L. GHG Emissions Related to Ethanol Transport and Distribution (T&D)

Transport Mode	GHG (gCO_2e/mmBtu)
Transported by Rail	2,102
Distributed by Heavy Duty Truck	734
Total (gCO_2e/mmBtu)	**2,836**
Total (gCO_2e/MJ)	**2.7**

ENERGY AND GREENHOUSE GASES CREDITS

In cellulosic ethanol plants, cellulose in the trees is converted into ethanol through enzymatic process. The lignin portion of the trees can be burned in ethanol plants to provide needed steam. Co-generation systems can be employed to generate both steam and electricity from lignin. Some amount of extra electricity can be generated in cellulosic plants and be exported to the electric grid. U. S. average electric mix is used in the calculations. Table M provides a summary of energy credits generated by the co-generation electricity. Complete details of the calculation are provided in Appendix A. GHG emission credits corresponding to the energy credits are provided in Table N.

Table M. Co-Generation Electricity Credits from Farmed Trees Ethanol Plants

	Energy Credit (Btu/gal)	Energy Credit (Btu/mmBtu)
Total generated electricity credit for farmed trees ethanol production	-3,592	**-47,059**

Table N. GHG Emission Credits from Co-generation

Emissions	g/mmBtu
CH_4	-12.9
N_2O	-0.1
CO_2	-10,361
Converted to GHG (gCO$_2$e/mmBtu)	-6,388
Converted to GHG (gCO$_2$e/MJ)	**-10.2**

TTW DETAILS

Anhydrous ethanol is considered as not being used directly as a fuel in California. Hence TTW emissions from anhydrous ethanol are not considered here. From a CO_2 perspective, since atmospheric CO_2 was fixed by the plant during its growth, CO_2 release from combustion is considered GHG neutral for farmed trees ethanol.

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APPENDIX A

SECTION 1. TREES FARMING

1.1 Energy Use for Cultivation of Farmed Trees

This section presents the direct farming energy inputs for trees cultivation. For trees cultivation, the CA-GREET model calculates energy and emissions based on the quantity of fuel (Btu) and chemicals used per quantity of product (dry ton of farmed trees), rather than using energy efficiencies, as the petroleum pathways in CA-GREET. The total input energy per dry ton of farmed trees is **234,770** (CA-GREET default) with the mix of fuel types shown in Table 1.01. The trees farming energy input is from the original GREET 1.5[4].

Table 1.01 Primary Energy Inputs by Fuel/Energy Input Type for Cultivation of Farmed Trees

Fuel Type	Fuel Share	Formula	Primary Energy Input (Btu/dry ton)
Diesel fuel	94.3%	94.3%*234,770	221,388
Electricity	5.7%	5.7%*234,770	13,382
Direct Energy Consumption for Cultivation of Farmed Trees (Btu/dry ton)			**234,770**

The energy inputs are direct inputs and not total energy required. CA-GREET accounts for the 'upstream' energy associated with fuels by multiplying with appropriate factors which are shown in Table 1.02. Actual values used to calculate total energy in Table 1.02 are shown in Table 1.03. Table 1.04 provides additional details for values used in Table 1.03.

Table 1.02 Calculating Total Energy Input by Fuel for Cultivation of Farmed Trees

Fuel Type	Formula	Total Energy
Diesel fuel	$A*[1+((B*C)+D)]/10^6$	257,478
Electricity	$E*(F+G)/10^6$	35,412
Total Energy for Cultivation of Farmed Trees (Btu/dry ton)		292,904
Total Energy for Cultivation of Farmed Trees (Btu/mmBtu)		**42,637**

Note: Anhydrous ethanol is "neat" fuel, typically 99.6% pure ethanol. The energy use for anhydrous ethanol is calculated from:
(Energy trees farming (Btu/dry ton) / (Ethanol Yield (gal/dry ton) * LHV of Anhydrous Ethanol (Btu/gal)))*10^6
Where: LHV of anhydrous ethanol is 76,330 Btu/gal.
Ethanol yields for trees ethanol are assumed to be 90 gal/dry ton as CA-GREET default.
(292,904 (Btu/dry ton) / (90 (gal/dry ton)76,330 (Btu/gal))) x 10^6 = **42,637** Btu/mmBtu

Table 1.03 Values Used in Table 1.02

Factor	Description	Value	Reference
A	Direct Diesel input	221,388 Btu/dry ton	calculated in Table 1.01
B	Crude energy	39,212 Btu/mmBtu	CA-GREET calculated – Cell B183 *Petroleum* tab
C	Diesel loss factor	1.0	CA-GREET default value
D	Conventional Diesel energy	123,805 Btu/mmBtu	CA-GREET calculated - Cell K183 *Petroleum* tab
E	Direct electricity input	13,382 Btu/dry ton	calculated in Table 1.01
F	Stationary electricity feedstock production	85,708 Btu/mmBtu	CA-GREET calculated - Cell B84 *Electricity* tab
G	Stationary electricity fuel consumption	2,561,534 Btu/mmBtu	CA-GREET calculated - Cell C84 *Electricity* tab

The factors listed in Table 1.03 are derived from the energy contributions of all other fuels that were used to produce ethanol. Those fuels are shown in Table 1.04 below, in two components: WTT energy (E) and Specific Energy (S) for each fuel type.

Table 1.04 Energy Consumption in the WTT Process and Specific Energy (from Upstream Sources)

	WTT energy (Btu input/mmBtu product)	S: Specific Energy (Btu input/Btu product)
Crude CR	WTT CR = 28,285 (CA-GREET calculated)	S CR = $1 + $ WTT CR$/10^6$ = 1.028
B	WTT Crude = WTT CR*LF T&D + WTT Crude T&D + WTT Crude Storage= 28,285*1 +10,926 + 0 = 39,212	LF T&D =Loss Factor for Transport and Distribution = 1.00 (CA-GREET default) WTT Crude T&D= 10,926 (CA-GREET calculated) WTT Crude Storage = 0 (CA-GREET default)
D	WTT Diesel = 123,805 (CA-GREET calculated)	S Diesel = 1+ (WTT Crude*Loss Factor Diesel+ WTT Diesel)/ 10^6 = 1.23. Loss Factor for diesel = 1 (CA-GREET calculation: cell B170 – *T&D* tab).
Electricity		S Electricity = (WTT feedstock +WTT fuel)/ 10^6 = 2.65 (CA-GREET calculation: cell R170 – *T&D* tab).
F	WTT feedstock production = 85,708 CA-GREET calculated)	
G	WTT feedstock consumption= 2,561,534 (CA-GREET calculated)	

Note:
WTT CR: WTT energy for Crude Oil Recovery, of self use of crude oil at the well, not includes T&D.
WTT Crude Storage: WTT energy of Crude storage

1.2 GHG Emissions from Cultivation of Farmed Trees

CA-GREET calculates carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions for each component of the pathway and uses IPCC[2] Global Warming Potentials (GWPs) to calculate CO_2 equivalent values for methane and nitrous oxide (see Table 1.05). For VOC and CO, CA-GREET uses a carbon ratio to calculate CO_2 equivalent values which are detailed in a note below Table 1.05. These are based on the oxidation of CO and VOC to CO_2 in the atmosphere. The GHG emissions resulting from fuel use in the EtOH production process is shown in Table 1.06. All emission factors listed are CA-GREET default values.

Table 1.05 Global Warming Potentials for Gases[5]

GHG Species	GWP (relative to CO_2)
CO_2	1
CH_4	25
N_2O	298

Note: values from mmBtu to MJ have been calculated using 1 mmBtu = (1/1055) MJ
Carbon ratio of VOC = 0.85 grams so CO_2/MJ = grams VOC/mmBtu*(0.85)*(44/12) = 3.1
Carbon ratio of CO = 0.43 grams so CO_2/MJ = grams CO/mmBtu*(0.43)*(44/12) = 1.6
where 44 and 12 are molecular weights of CO_2 and C, respectively.

Table 1.06 CO_2 Emission Factors from Upstream Sources

	EF= emissions factors for WTT CO_2 (gCO_2/mmBtu fuel output)	SE: Specific Emission (gCO_2e/mmBtu fuel output)
Crude CR	EF CR = 2,961	SE CR = (1+EF CR)/10^6
Crude	EF Crude = EF CR *LF T&D + EF Crude T&D + EF Crude Storage + (VOC and CO conversion) = 2,961*1 +875 +0 + (6.5*.85/.27) + (27.5*.43/.27) = 3,868	
Conventional Diesel	EF Diesel = 9,389	SE Diesel = [1+(EFCrude*Loss Factor Diesel+EF Diesel)]/10^6
Electricity	EF feedstock = 6,833, EF fuel = 213,458	SE Electricity = (EF feedstock +EF fuel)/10^6

Note:
CR: Crude Recovery
LF: Loss Factor
EF: Emission Factor
NG: Natural Gas

The greenhouse gas emissions attributable to energy use are determined separately for CO_2, CH_4 and N_2O in CA-GREET using the direct energy inputs presented in Section 1.1 (Btu/dry ton) and the combustion and upstream emissions for the energy input. CA-GREET calculates the emissions for each fossil fuel input by multiplying fuel input (Btu/dry ton) by the total emissions from combustion, crude production and fuel

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[2] IPCC: Intergovernmental Panel on Climate Change a scientific intergovernmental body tasked to evaluate the risk of climate change caused by human activity established by United Nations in 1988.

production. The electricity emissions are calculated by multiplying the electricity input (Btu/dry ton) by the total (feedstock plus fuel) emissions associated with the chosen electricity mix (from the *Electricity* Tab in CA-GREET model). Table 1.07 below shows equations and calculated values by fuel type for trees farming CO_2 emissions. Equations and values for CH_4 and N_2O are not shown, but use the same structure. Table 1.08 provides values for parameters used in the equations in Table 1.07.

Table 1.07 CA-GREET Calculations for CO_2 Emissions from Cultivation of Farmed Trees (from Upstream Sources)

Fuel	Formula	CO_2 Emissions (g/dry ton)
Diesel	$[(A)*[(B)*(C) + (D)*(E)+(F)*(G)+(H)*(I)+(J)*(K)+(L)]]/10^6$	20,033
Electricity	$[(M)*[(N)+(O)]]/10^6$	2,947
Total CO_2 emissions (g/ton)		**22,981**
Conversion to total CO_2 emissions (g/mmBtu)		**3,345**
Conversion to (g/MJ)		**3.2**

Note: The calculations for CH_4 and N_2O are analogous. Relevant parameters here are calculated values in CA-GREET, except for technology shares, which are direct inputs.

To convert (g/dry ton) to (g/mmBtu): (g/dry ton)/(Ethanol Yield (gal/dry ton) * LHV of Anhydrous Ethanol (Btu/gal))*10^6.

(where LHV of ethanol is 76,330 Btu/gal and ethanol yield is assumed to be 90 gal/dry ton)

Table 1.08. CA-GREET Calculations for CO_2 Emissions Associated with Trees Cultivation

Fuel	Relevant Parameters*	Reference
A	Diesel input = 221,388 Btu/dry ton	Table 1.01
B	% Fuel share diesel boiler = 0%	CA-GREET default
C	Boiler CO_2 emissions = 78,167 g/mmBtu	CA-GREET default
D	% Fuel share diesel stationary engine = 20%	CA-GREET default
E	IC Engine CO_2 Emissions =77,401 g/mmBtu	CA-GREET default
F	% Fuel share diesel turbine = 0%	CA-GREET default
G	Turbine CO_2 emissions 78,179 g/mmBtu	CA-GREET default
H	% Fuel share diesel tractor = 80%	CA-GREET default
I	Tractor CO_2 emissions = 77,204 g/mmBtu	CA-GREET default
J	Crude production CO_2 emissions = 3,868 g/mmBtu	Table 1.06
K	Diesel loss factor = 1.0	CA-GREET default
L	Diesel production CO_2 emissions = 9,389g/mmBtu	Table 1.06
M	Electricity input = 13,637 Btu/dry ton	Table 1.01
N	Electricity feedstock CO_2 emissions = 3,868 g/mmBtu	Table 1.06
O	Electricity fuel CO_2 emissions = 213,458 g/mmBtu	Table 1.06

Note: The calculations for CH_4 and N_2O are in similar ways but with different values of emission factors.

VOC, CO, CH_4, and N_2O emissions are calculated with the same equations, energy inputs, and loss factors as CO_2 emissions calculations shown in Table 1.07, but with different VOC, CO, CH_4, and N_2O emission factors. Table 1.09 shows the results of the calculations of VOC, CO, CH_4, and N_2O in (g/dry ton) then converted to g/mmBtu. CA-GREET has an exogenous credit for land use change emissions for CO_2 sequestered in soil from cultivation of farmed trees. For this document, this credit has not been considered and will need to be reviewed in the future.

Table 1.09 GHG Emissions from Trees Cultivation

| Emission Species	Emissions (g/dry ton)	GHG (g/mmBtu)	GHG (gCO$_2$e/mmBtu)
VOC	24.9	3.7	12.2
CO	94	13.7	21.5
CH$_4$	27.4	4.0	100
N$_2$O	0.3	0.05	13.5
CO$_2$	22,981	3,345	3,345
Total GHG (gCO$_2$e/mmBtu)			3,526
Total GHG (gCO$_2$e/MJ)			**3.34**

Note: Emissions in grams of gaseous species per dry ton. To convert all VOC, CO, CH$_4$ and N$_2$O (g/dry ton) to (g/mmBtu):

(g/mmBtu) = (g/dry ton)/(Ethanol Yield (gal/dry ton) / LHV of Ethanol (Btu/gal))*10^6

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SECTION 2. CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS
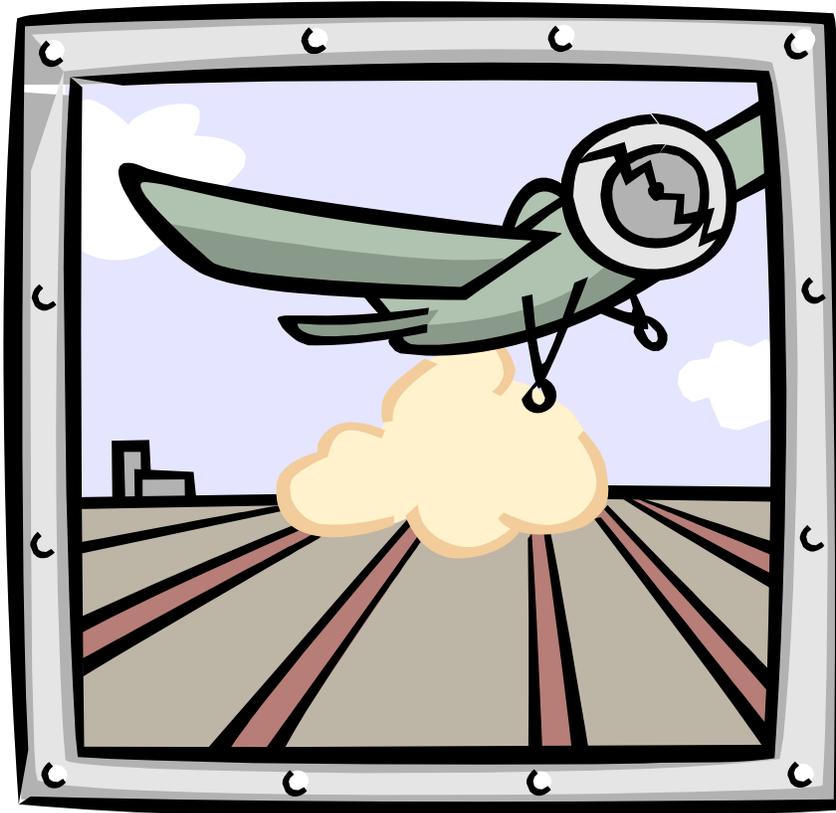
2.1 Energy Calculations for Production of Chemical Inputs

Chemical inputs, including fertilizers, herbicide and insecticide, are input on a g-nutrient/dry ton (fertilizer) or g-product/dry ton (herbicide and pesticide) basis. Table 2.01 below presents the CA-GREET chemical inputs per dry ton of farmed trees, the total energy required to produce the chemical product and the calculated upstream energy required to produce a dry ton of farmed trees using these inputs. Both chemical input values and product energy values are CA-GREET defaults.

Table 2.01 Trees Farming Chemical Inputs (g/bushel), Product Input Energy (Btu/g), and WTT Energy

Chemical Type	Chemical Input (g/dry ton)	Product Input Energy (Btu/g)	WTT Energy (Btu/dry ton)	WTT Energy (Btu/mmBtu)
Nitrogen Fertilizer	709	45.8	32,499	4,731
Phosphate Fertilizer	189	13.3	2,516	366
Potash	331	8.4	2,786	406
Herbicide (average)	24	265	6,333	922
Insecticide (average)	2	312	625	91
Total				**6,515**

Note: Ethanol yield of farmed trees is assumed to be 90 gal/dry ton in CA-GREET.
WTT Energy is calculated as: WTT energy = chemical input (g/dry ton)* product input energy (Btu/g).

CA-GREET models nitrogen fertilizer as a weighted average of ammonia (70.7%), urea (21.1%) and ammonium nitrate (8.2%) fertilizer. As Table 2.01 shows, nitrogen fertilizer input accounts for more than 2/3 of total chemical energy input. The herbicide production energy is a weighted average of four types of herbicides used: atrazine (31.2%), metolachlor (28.1%), acetochlor (23.6%) and cyanazine (17.1%). The insecticide inputs represent an "average" insecticide, rather than an explicitly weighted average of specific insecticides. The energy required to produce nitrogen fertilizers, herbicides or pesticides does not vary significantly by category, attesting to the validity of using average energy inputs.

2.2 GHG Calculation for Production of Chemical Inputs

This component includes all of upstream emissions related to the manufacturing of agricultural chemical products. Upstream emissions are calculated in CA-GREET per ton of product, including the production, process and transportation emissions associated with manufacturing chemicals; these intermediate calculations take place in the *Ag Inputs* worksheet of the model. These values are converted to emissions per ton of nutrient using the ratio of nutrient to product. At this level, nitrogen fertilizer greenhouse emissions are modeled as a weighted average of 3 types of N-fertilizers modeled in CA-GREET. Finally, energy and emissions are converted to Btu or grams greenhouse gases per gram of nutrient (fertilizer) or product (herbicide and pesticide).

At this point, average herbicide emissions are calculated using a weighted average of 4 herbicides and pesticide emissions are based on a single pesticide type. Table 2.02 below shows the greenhouse emissions for agricultural chemicals in grams per gram of nutrient for fertilizers and per gram of product for herbicides and pesticides. The formulas are complex and not shown here since agricultural inputs apply to large variety of crop cultivation and are not specific to trees cultivation.

Table 2.02 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

GHG Type	Nitrogen (weighted average)	P_2O_5	K_2O	Herbicide (weighted average)	Pesticide
	g/g nutrient			g/g product	
CH_4	0.0021	0.0014	0.0009	0.03	0.031
N_2O	0.0016	<0.001	<0.001	<0.001	0.0002
CO_2	2.39	0.98	0.66	20.6	24.0
GHGs (g/g)	**3.0**	**1.2**	**0.7**	**21.3**	**24.8**

The greenhouse emissions of agricultural inputs are multiplied by chemical input factors (g/dry ton) in the *Ethanol* worksheet and a loss factor from the *Ag Inputs* worksheet to yield fertilizer emissions in grams per dry ton of farmed trees. Table 2.03 below shows the calculations for CO_2 emissions associated with the use of chemical inputs in g/dry ton of farmed trees produced. Table 2.04 details the values used in calculations in Table 2.03. These calculations exclude VOC and CO emissions converted to CO_2 (calculated in emission summary in CA-GREET). The equations for CH_4 and N_2O are analogous to these calculations and are not shown. Table 2.05 shows the emission results for all greenhouse gases for chemical use, based on the calculations shown in Table 2.03.

Table 2.03 Calculated CO_2 Emissions Associated with Production of Agricultural Chemicals

Chemical Product	Formula	CO_2 Emissions	
		g/dry ton	g/mmBtu
Nitrogen (weighted average)	(A)*(B)*(C)	1,931	281
P_2O_5	(D)*(E)*(F)	185	27
K_2O	(G)*(H)*(I)	219	32
Herbicide	(M)* (N)*(O)	495	72
Pesticide	(P)*(Q)*(R)	48	6
Total CO_2 emissions		2,879	419
Total g/CO_2e/MJ			**0.49**

Table 2.04 Calculated CO_2 Emissions (g/g) Associated with Production of Agricultural Chemicals

Chemical Product	Relevant Parameters	Reference
A	Nitrogen input = 709 g/dry ton	CA-GREET default
B	Nitrogen chemical cycle emissions = 2.39 g/g	CA-GREET default
C	Nitrogen loss factor = 1.0	CA-GREET default
D	P_2O_5 input = 189 g/dry ton	CA-GREET default
E	P_2O_5 chemical cycle emissions = 0.98 g/g	CA-GREET default
F	P_2O_5 loss factor = 1.0	CA-GREET default
G	K_2O input = 331 g/dry ton	CA-GREET default
H	K_2O chemical cycle emissions = 0.66 g/g	CA-GREET default
I	K_2O loss factor = 1.0	CA-GREET default
M	Herbicide input = 24 g/dry ton	CA-GREET default
N	Herbicide chemical cycle emissions = 20.63 g/g	CA-GREET default
O	Herbicide loss factor = 1.0	CA-GREET default
P	Pesticide input = 2 g/dry ton	CA-GREET default
Q	Pesticide chemical cycle emissions = 24.0 g/g	CA-GREET default
R	Pesticide loss factor = 1.0	CA-GREET default

Note: Loss Factor occurs during transportation due to evaporation, venting, etc.

Table 2.05 shows the emission results (g/dry ton) for all GHG emissions for production of chemicals used in agriculture based on the calculations shown in Table 2.03. The CH_4 and N_2O emissions results shown in Table 2.05 are calculated with the same formula as CO_2 emission calculations, except that CO_2 emission factors are replaced by CH_4 and N_2O emission factors. Table 2.05 also shows the WTT emissions.

Table 2.05 Calculated GHG Emissions from Production of Agricultural Chemicals

GHG Species	Nitrogen (weighted average)	P_2O_5	K_2O	Herbicide (weighted average)	Pesticide	Total
	g/dry ton			g/dry ton		
CH_4	1.48	0.27	0.29	0.53	0.06	
N_2O	1.15	0.002	0.002	0.003	<0.001	
CO_2	1,931	185	219	495	48	
GHGs (g/dry ton)	2,332	193	227	513	50	3,035
GHGs (g/mmBtu)	339	28	33	75	7	482
GHGs (g/MJ)	**0.32**	**0.03**	**0.03**	**0.07**	**0.01**	**0.46**

Note: To convert (g/dry ton) to (g/mmBtu):
(g/dry ton)/(Ethanol Yield (gal/ton) * LHV of Anhydrous Ethanol (Btu/gal))*10^6 .
e.g.: from the Nitrogen GHG above : 2,332 (g/ton)/(90(gal/ton)*76,330 Btu/gal))*$10^{6\ =}$ 339 (g/mmBtu)

CA-GREET also calculates direct field and downstream N_2O emissions resulting from nitrogen fertilizer input. Table 2.06 below shows the two main inputs: fertilizer input (g/dry ton) and percent conversion of N-input to N_2O. This table shows the N_2O emissions on an energy basis (g/mmBtu and g/MJ anhydrous ethanol) and N_2O emissions associated with trees production are calculated the same way, using the relevant ethanol yield value (see note below Table 2.05). CA-GREET model assumes 1.3% of fertilizer-N is ultimately converted to N_2O. The calculation also uses the mass ratio of N_2O to N_2 (44/28). N_2 is used rather than N because two fixed N atoms are required for every N_2O molecule formed. This is summarized in Table 2.06. The total GHG emissions for agricultural chemicals are detailed in Table 2.07.

Table 2.06 Inputs and Calculated Emissions for Soil N_2O from Trees Cultivation

Fertilizer N input (g/dry ton)	Percent conversion to N_2O-N	N_2O formed/ N_2O-N (g/g)	N_2O Emissions (g/dry ton)	GHG Emissions (g/mmBtu)	GHG Emissions (g/MJ)
709	1.3%	(44/28)=1.57	14.8	640	**0.6**

Note: Soil N_2O emissions = (709 g N/ton)(1.3%)(44 g N_2O/28 g N_2) = 14.5 gN_2O/ton

Table 2.07 Total GHG Emissions for Agricultural Chemical Use for Farmed Trees Ethanol

Ethanol Pathway	Fertilizers	Herbicide	Pesticide	Soil N_2O	Total
GHGs (gCO_2e/MJ)	0.32	0.03	0.03	0.6	**1.1**

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SECTION 3. FARMED TREES TRANSPORT
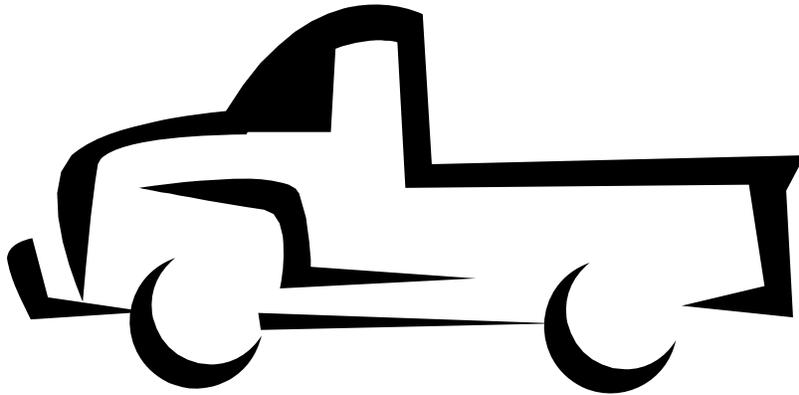
3.1 Energy for Transportation of Farmed Trees

CA-GREET calculates the total energy needed (Btu/ton) to transport farmed trees from the field to the fuel production facility using heavy duty trucks. Table 3.01 below shows the farmed trees transportation distance and energy inputs. The calculations are based on heavy duty truck capacity of 15 tons. The moisture content of the trees is assumed at 25% of the weight. The default distance transport distance 40 miles from the stack to the ethanol plant. CA-GREET calculates the diesel energy per ton mile based cargo capacity of the truck and its fuel economy and assumes that truck trips carrying farmed trees and returning empty use the same energy. All values are CA-GREET default values.

Table 3.01 Inputs for Transporting Farmed Trees

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	Capacity (tons)	Fuel Consumption (mi/gal)	Energy Consumption of Truck (Btu/mi)	Shares of Diesel Used
Field to Ethanol Plant Heavy Duty Truck	1,511	40	17	5	25,690	100%

The calculated farmed trees transport energy is shown below in Table 3.02 using the values in Table 3.01.

Table 3.02 Transport Energy for Farmed Trees

Transport Mode	Energy Consumption (Btu/ton)	Energy Consumption (Btu/dry ton)
Field to Ethanol Plant by Heavy Duty Truck (with 25% tree moisture content)	148,936	148,936 Btu/ton/(1-25%) = 198,591
Total converted to Btu/mmBtu		**28,907 (Btu/mmBtu)**

Note:
- For Heavy Duty Truck Transport Energy Consumption Calculation:

(40 miles one-way distance)*(1,511 Btu/ton-mile origin to destination + 1,511 Btu/ton-mile back-haul)*(Diesel share 100%)*(1+Diesel WTT Energy 0.232 Btu/Btu) = 148,936 Btu/ton (see table 1.06 for specific energy)
- Convert to Btu/mmBtu: 198,591 Btu/ton)/(90 gal/ton * 76,330 Btu/gal) * 10^6 = 28,907 Btu/mmBtu

3.2 GHG Calculations from Transportation of Farmed Trees

GHG emissions from transporting farmed trees are calculated using energy values from section 3.1 with the same transportation mode, miles traveled, etc. as indicated by Table 3.01 above. Tables 3.03 detail key assumptions of calculating GHG emissions from transporting farmed trees. All values used in calculations are CA-GREET default values.

Table 3.03 Key Assumptions in Calculating GHG Emissions from Transporting Farmed Trees

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance 1-way (mi)	CO_2 Emission Factors of Truck (g/mi)	CO_2 Emission Factors of Diesel used as transportation fuel (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
Field to Ethanol Plant by Heavy Duty Truck	1,511	40	1,999	77,809 Origin to Destination	11,368
				77,912 Return Trip	

The calculated transport energy on g/ton and dry ton of farmed trees basis, then converted to g/mmBtu is shown in Table 3.04 below.

Table 3.04 Transport of Farmed Trees- CO_2 Emissions

Transport Mode	CO_2 Emission (g/ton)	CO_2 Emission (g/mmBtu)
Field to Ethanol Plant by Heavy Duty Truck	15,158	2,206
Total (gCO₂/MJ)		**2.1**

Note: Example formula to calculate CO_2 emission of Heavy Duty Truck above:
- For origin to destination and return:

((77,809 g/mmBtu diesel CO_2 EF for HDD truck+ 16,175 g/mmBtu diesel CO_2 EF)*100% diesel used)*1,511 (Btu/ton-mile) *40 miles/(10^6 mmBtu/Btu) = 5,684 g/ton
- Adjusted to 25% moisture content in the trees and both ways truck travel:

2* 5,684/(1-25%) = 15,158 g/ton

Similarly, CH_4, N_2O, VOC, and CO are calculated the same way (with different emission factors for each species) and shown in Table 3.05. Then all emissions are converted to CO_2 equivalent based as shown in Tables 3.06.

Table 3.05 Transport of Farmed Trees – Other GHG Emissions in g/mmBtu

Transport Mode	CH_4	N_2O	VOC	CO
Field to Ethanol Plant by Heavy Duty Truck	2.7	0.05	0.95	4.37

Note: Example formula to calculate CH_4 emission of Heavy Duty Truck above (using CH_4 Emission Factor):

- For Origin to Destination and return:

$((1.524$ g/mmBtu $+ 112.1$ g/mmBtu$)+100\%$ diesel used$)*1,511$ (Btu/ton-mile) $*40$ miles/$(10^6$ mmBtu/Btu$) = 6.86$ g/ton

- Adjusted to 25% moisture content in the trees: $(2*6.86)/(1-25\%) = 18.3$ g/ton
- Converted to g/mmBtu: $[18.3$ g/ton $/(90$ gal/ton $* 76,330$ Btu/gal$)] * 10^6 = 2.7$ g/mmBtu

Table 3.06 Transport of Farmed Trees–Total GHG Emissions

Transport Mode	CH_4 (gCO$_2$e/ mmBtu)	N_2O (gCO$_2$e/ mmBtu)	VOC and CO Conversion (g/mmBtu)	CO_2 (g/mmBtu)	GHG (gCO$_2$e/ mmBtu)	GHG (gCO$_2$e/ MJ)
Stack to Ethanol Plant Heavy Duty Truck	2.7*25 = 67.5	0.05*29 8 = 14.9	**VOC:** 0.95*0.85/0. 27 = 2.99 **CO:** 3.84*0.43/0. 27 = 6.95	2,138	2,222	**2.1**
Total GHG (gCO$_2$e/MJ)						**2.1**

SECTION 4. ETHANOL PRODUCTION

4.1 Ethanol Production by Fermentation

Ethanol production from farmed trees is via fermentation. Cellulosic content of the trees is converted into ethanol through enzymatic processes. The lignin portion of the trees that is not utilized by the enzymes can be burned to provide needed process energy. To calculate the ethanol production, CA-GREET uses energy input values for farmed trees ethanol in Btu/gallon of anhydrous ethanol and uses fuel shares to allocate this direct energy input to process fuels. The fuels used in the ethanol production process are diesel fuel for boilers, engines, and turbines and the energy embedded in the feedstock (farmed trees) itself. Table 4.01 below shows the ethanol production diesel shares and energy inputs per gallon of anhydrous ethanol. Co-generation systems can be employed to generate both steam and electricity from lignin of the trees for use on-site. Some amount of extra electricity can be generated in cellulosic plants and be exported to the electric grid. In the ethanol plant, 1.145 kWh/gal is credited as a CA-GREET default value. For this pathway in this document, credit is provided for both process energy and co-generated electricity. The average U.S. electric mix is used in the calculations.

Table 4.01 Primary Energy Inputs (Btu/gallon) for Ethanol Production from Farmed Trees

	Fuel Share	**Primary Energy Input**
Conventional Diesel	<0.01%	389 Btu/gal
Farmed trees	100%	110,851Btu/gal
Ethanol extracted credit from burning trees		-76,330 Btu/gal

The CA-GREET assumes that the mass share of trees that is used for ethanol is 55%. The remaining mass of the trees (45%) goes towards combustion for power and steam generation. CA-GREET uses the direct, primary energy inputs for ethanol production to calculate the total energy required to deliver each primary energy input. Table 4.02 below shows the CA-GREET equations, parameters and energy inputs for ethanol production.

Table 4.02. Details of Production Energy Use for Ethanol from Farmed Trees

Fuel Type	Formula	Relevant Parameters	Total Energy (Btu/gal)
Diesel	CA-GREET Default	Direct diesel energy used in process	337
	Direct diesel energy *((Crude*Loss Factor) / 10^6 = (337Btu/gal * 39,212 Btu/mmBtu*1)/10^6	Energy upstream from crude (see Table 1.04)	10.6
	Direct diesel energy * WWT of diesel = (337 Btu/gal * 123,805 Btu/mmBtu*1)/10^6	Energy WTT of diesel	44.2
Farmed Trees	(1/90 tons/gal)*(LHV of trees 16,811,000 Btu/ton)	farmed tree used as feedstock: for 1 gallon of ethanol, 1/90 or 0.0111 tons of trees needed	110,459
Loss		Loss Factor in the process	1.0005
Total energy input for ethanol production (Btu/gal)			110,851
Total energy input (Converted to Btu/mmBtu)	**110,8751Btu/gal*1.0005/76,330 Btu/gal *10^6**		1,452,984

4.2 Energy Credit from Co-generation of Electricity

In the tree ethanol plant, 1.145 kWh/gal is the amount electricity credited as a CA-GREET default value. Co-generation systems can be employed to generate both steam and electricity from lignin of the trees for use on-site. Some amount of extra electricity can be generated in cellulosic plants and be exported to the electric grid as show in table 4.03.

Table 4.03 Energy Credit from Co-generation System

Parameter	Formula	Calculations*	Values (Btu/gal)
Power from Co-generation	CA-GREET default	1.145 kWh/gal *3,412 Btu/kWh = 3,907 Btu/gal	3,907
Displaced Electric Power	CA-GREET default	(100%-8.1%)*3907	3,590
Loss Factor of the system	CA-GREET default	1.0005	
Total Credit (Btu/gal) = -(3,590)*1.0005			-3592
Co-generation Credit Convert to Btu/mmBtu (as ethanol)			**-47,059**

Note: Transmission loss = 8.1% assumed for electricity.

4.3 GHG Emissions from Ethanol Production by Fermentation

GHG from ethanol production is calculated based on the assumptions in Table 4.04 below and the results are shown in Table 4.05. As indicated in the previous section, the majority of direct energy used is from trees burning (99.9%), plus a small amount of diesel used in the process. These shares of energy are multiplied with the GHG emission factors of equipment used in the production process.

Table 4.04 Process Shares and Emission Factors (EF) of Ethanol Production Equipment by CA-GREET Default

EtOH Production Equipment and Fuel Used	% Shares of Equip. Usage	CO_2 EF (g/mmBtu of fuel burned)	VOC EF	CO EF	CH_4 EF	N_2O EF	Assumed % of fuels used	Direct Energy Use (Btu/gal)
large industrial boiler	33%	78,167	1.17	16.69	0.18	0.19	0.1%	337*1.0005 = 337.2
stationary engine	33%	77,401	70.44	361	3.9	2		
diesel turbine	34%	78,179	1.33	8.71	0.84	2		
diesel WTT energy	See table 4.02						0.1%	54.8
farmed trees small boiler	100%	102,241	5.34	76.8	3.83	11	99.9%	110,459*1.0005 = 110,514
Total Energy Used (after applied loss factor) (Btu/gal)								**110,895**

Table 4.05 Calculated CO_2 Emissions (g/gal) for Ethanol Production from Farmed Trees Using CO_2 Factors from Table 4.04

	Calculations CO_2 in g/gal		Conversion to CO_2 (g/mmBtu)	Results
From Diesel combustion				
large industrial boiler	$337.2*33\%*78,167/10^6 = 8.7$			
stationary engine	$337.2*33\%*77,401/10^6 = 8.6$	26.3	(26.3 g/gal)/(76,330 Btu/gal)$*10^6$	344
diesel turbine	$337.2*34\%*78,179/10^6 = 9$			
WTT diesel	$337.2* (2,899*1+8,987) /10^6 = 4$ (see table 1.06 for diesel WTT)	4	(4 g/gal)/(76,330 Btu/gal)$*10^6$	44
From Trees Energy				
farmed trees small boiler	$16,811,000*(1/90)* (100\%-55\%)* 102,224/ 10^6$	8,592	(8,606 g/gal)/(76,330 Btu/gal)$*10^6$	112,564
Ethanol Extracted from Farmed Trees				
CO_2 credit from extracted ethanol	$51.7\%C * 2000$ lb/ton $* 454 * 44/12 * (1/90)*(100\%-55\%)$	-8,606	-8,606/76,330 Btu/gal$*10^6$	-112,747

Similar calculations are made for VOC, CO, CH_4, and N_2O. Total GHG emissions for ethanol production are shown in Table 4.07 below.

Table 4.06. GHG Emissions for Ethanol Production by Fermentation

GHG Species	GHG Emissions g/gal	GHG Emissions g/mmBtu
VOC	0.46	6
CO	6.5	85.2
CH_4	0.88	11.5
N_2O	0.52	6.85
CO_2	8,623	112,972
CO_2 from atmosphere	-8,606	-112,751
Total GHGs (gCO_2e/mmBtu)	206.3	2,702
Loss factor x GHG	206.4	2,703
Total GHGs (gCO_2e/MJ)		**2.56**

Note: Loss factor = 1.0005

GHGs also are credited from the co-generation system as shown in Table 4.08 below.

Table 4.07 GHG Emission Credits from Co-Generation Electricity in Cellulosic Ethanol Plant

Emissions	g/gal	g/mmBtu
CH_4 (g/gal)	-0.926	-12.9
N_2O (g/gal)	-0.008	-0.1
CO_2 (g/gal)	-791	-10,361
GHG (gCO_2e/mmBtu)	-819	-6,388
GHG (gCO_2e/MJ)	**-10.2**	**-10.2**

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SECTION 5. ETHANOL TRANSPORT AND DISTRIBUTION

5.1 Energy for Ethanol Transportation and Distribution

Transport from the ethanol plant to the bulk terminal or storage facility is accomplished primarily by rail (with short truck delivery to terminal or storage facility). The transport distance based on AB1007 analysis is 1,400 miles by rail and 40 miles by truck. The local distribution step involves transporting ethanol to a gasoline blending terminal where it is blended with gasoline to produce CaRFG. The estimated distribution distance is 50 miles based on the AB1007 analysis.

Instead of calculating the WTT values on a per ton basis as CA-GREET does for the farmed trees transport component, CA-GREET calculates WTT energy required per mmBtu of fuel (anhydrous ethanol) transported. Table 5.01 below shows the major inputs used in calculating transport energy and Table 5.02 presents the CA-GREET formulas used to calculate the ethanol transport energy for each transport mode.

Table 5.01 Inputs and Calculated Fuel Cycle Energy Requirements for Ethanol Transport to Bulk Terminals

Transport	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	Capacity (tons)	Fuel Used (mi/gal)	Energy Used of Truck (Btu/mi)	Shares of Diesel Used	% Fuel Transported by Mode
Transportation by Rail	370	1,400	n/a	n/a	n/a	100%	100%
Distribution by HDD Truck	1,028	30	25	5.0	25,690	100%	100%

Table 5.02 CA-GREET Calculations for Ethanol Transport and Distribution Energy (Btu/mmBtu) by Transport Mode

Transport Mode	CA-GREET Formula	Relevant Parameters	Btu/mmBtu
Transport By Rail	10^6/(76330)*(2988)/((g/lb)*(lb/ton)*(1400)*(370)*((100%)*(1+0.232))	Ethanol LHV = 76,330 Btu/gal Ethanol density = 2,988 g/gal Miles traveled = 1,400 Diesel energy intensity of rail = 370 Btu/ton-mile Diesel shares = 100% Diesel energy as transportation fuel = 0.232	27,512
Distr. By Truck	(10^6)/(76330)*(B)/((g/lb)*(lb/ton)*(30)*2*(1028)*((100%)*(1+0.232))*80%	Miles traveled = 30 Diesel energy intensity of truck = 1,028 Btu/ton-mile 80% distribution by truck (20% assumed directly by pipeline)	2,620
T&D Total (Btu/mmBtu)			**30,132**

Note: The energy intensity for heavy duty trucks is multiplied by 2 to account for return trip.

5.2 GHG Calculations from Ethanol Transportation and Distribution

Similar to Farmed trees T&D, ethanol T&D to bulk terminal is assumed in CA-GREET using rail cars and then to destination by truck. All the key assumptions are the same as T&D of farmed trees and are shown in Table 5.03.

Table 5.03 Key Assumptions in Calculating GHG Emissions from EtOH Transportation

Transport Mode	1-way Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	CO_2 Emission Factors (g/mi)	CO_2 Emission Factors of Diesel used as transportation fuel (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
100% Rail	370	1,400		13,257	77,664
100% Heavy Duty Truck	1,713	40	1,999	13,257	77,798

Note: Assumed all locomotives use diesel

The results are shown below in Table 5.04. The WTT emissions shown in the Table for each GHG species is calculated in the *T&D* tab of CA-GREET. The equation for CO_2 from rail is shown below and the calculations for the other transport modes and GHG gases are done similarly. Note that only one-way rail emissions are counted, whereas an extra term exists in the calculation for truck transport to account for the return truck trip; emissions from the return trip are assumed to be equal to emissions for the trip from the origin to destination. Table 5.04 also provides CH_4 and N_2O emissions.

Rail CO_2 emissions = (Ethanol density 2,988 g/gal)/(Ethanol LHV 76,330 Btu/gal)/[(454 g/lb)*(2,000 lbs/ton)]*[(Diesel emission factor 77,664 g/Btu)+(Diesel WTT emissions 11,187 g/mmBtu)]*(370 Btu/ton-mile)*(1400 miles) = 2,030 g/mmBtu

Truck CO_2 emissions are calculated the same way with its own emission factors:

Table 5.04 EtOH Transport – GHGs Emissions in g CO_2e /mmBtu

Transport Mode	CO_2	CH_4 to CO_2e		N_2O to CO_2e		CO_2e
Transported by Rail	2,030	2.3	53.7	0.05	14.2	2102
Distributed by Heavy Duty Truck	723	0.7	20.4	0.005	6.7	734
Total	2,753	3.0	74.1	0.06	18.9	2,836
Total converted to (gCO$_2$e/MJ)						**2.7**

SECTION 6. EMISSIONS FROM ETHANOL COMBUSTION

6.1 GHG Calculations from Ethanol Combustion

Anhydrous ethanol is not used in CA directly as a fuel. It is blended with a denaturant before it is shipped from a production plant. The use of 10% by volume (nominal) of ethanol in CaRFG is detailed in the CaRFG pathway document[3]. Since CO_2 released from the combustion of ethanol was essentially 'fixed' by the plant during its growth, CO_2 emissions from combustion of ethanol derived from farmed trees is considered carbon-neutral. CH_4 and N_2O emissions when used in CaRFG are detailed in the CaRFG pathway document.

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[3] The lifecycle analysis of several fuel pathways are presented in the California Air Resources Board – Low Carbon Fuel Standard website: http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

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APPENDIX B
ETHANOL PATHWAY INPUT VALUES
(FROM FARMED TREES)

Ethanol made by farmed trees in Midwest and transported to California for blending

Parameters	Units	Values	Note
GHG Equivalent			
CO_2		1	
CH_4		23	
N_2O		296	
VOC		3.1	
CO		1.6	
Farmed Trees Farming			
Fuel Use Shares			
Diesel		94.3%	
Electricity		5.7%	
Cultivation Equipment Shares			
Diesel Farming Tractor		80%	
CO_2 Emission Factor	g/mmBtu	77,204	
Diesel Engine		20%	
CO_2 Emission Factor	g/mmBtu	77,401	
Farmed trees Farming			
Farmed trees energy use	Btu/ton	234,770	
Land Use CO_2 Emission from trees farming	g/dry ton	0	
Farmed trees T&D			
Transported from trees field to EtOH plant			
by heavy duty diesel truck	miles	40	1,713 Btu/mile-ton Energy Intensity
fuel consumption	mi/gal	5	capacity 15 tons/trip
CO_2 emission factor	g/mi	1,999	
Chemicals Inputs			
Nitrogen	g/dry ton	709	
NH3			
Production Efficiency		82.4%	
Shares in Nitrogen Production		70.7%	
CO_2 Emission Factor	g/g	2.475	
Urea			
Production Efficiency		46.7%	
Shares in Nitrogen Production		21.1%	
Ammonium Nitrate			
Production Efficiency		35%	
Shares in Nitrogen Production		8%	
P_2O_5	g/dry ton	189	
H_3PO_4			
Feedstock input	tons	n/a	
H_2SO_4			
Feedstock input	tons	2.674	
Phosphor Rock			
Feedstock input	tons	3.525	
K_2O	g/dry ton	331	
Herbicide	g/dry ton	24	
Pesticide	g/dry ton	2	

EtOH Production			
EtOH Yield	gal/dry ton	90	
Energy use		45,970	
Diesel Use		0.1%	
Commercial Boiler	g CO_2/mmBtu	78,167	33% usage
Diesel Engine	g CO_2/mmBtu	77,401	33% usage
Diesel Turbine	g CO_2/mmBtu	78,179	34% usage
Farmed trees used as fuel		99.9%	45% of farmed trees used as fuel
Boiler	g CO_2/mmBtu	102,241	
EtOH T&D			
Transported by rail	miles	1,400	370 Btu/mile-ton Energy Intensity
Transported by HHD truck	miles	40	1,028 Btu/mile-ton Energy Intensity both ways
Distributed by HHD truck	miles	30	1,028 Btu/mile-ton Energy Intensity both ways
Fuels Properties	**LHV (Btu/gal)**	**Density (g/gal)**	
Crude	129,670	3,205	
Residual Oil	140,353	3,752	
Conventional Diesel	128,450	3,167	
Conventional Gasoline	116,090	2,819	
CaRFG	111,289	2,828	
CARBOB	113,300	2,767	
Natural Gas	83,868	2,651	As liquid
EtOH	76,330	2,988	Anhydrous ethanol
EtOH	77,254	2,983	Denatured ethanol
Still Gas	128,590		
Farmed Trees	16,811,000	n/a	Btu/dry ton

[1]GREET Model: Argonne National Laboratory:
http://www.transportation.anl.gov/modeling_simulation/GREET/index.html
[2]California Assembly Bill AB 1007 Study: http://www.energy.ca.gov/ab1007
[3]CA_GREET Model (modified by Lifecycle Associates) released February 2009
(http://www.arb.ca.gov/fuels/lcfs/lcfs.htm)
[4]Wang, et al. (Aug 1999). "Transportation Fuel-Cycle Model ". Argonne, IL, prepared by Center for
Transportation Research, Argonne National Laboratory – section 4, p.66
[5]"*IPCC Technical Report 2007*" – Table TS-2 – page 33 (http://www.ipcc.ch/pdf/assessment-
report/ar4/wg1/ar4-wg1-ts.pdf)